Past and Present Fire Influences on Southwestern Ponderosa Pine Old Growth[1]

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Abstract--For centuries, the climate of the Southwest teamed with frequent natural fires to develop and maintain an open-structured ponderosa pine forest. Most pine regeneration died in competition with grasses or in the inevitable surface fires. Those that survived were sustained throughout the next several centuries by this fire sequence. Old-growth ponderosa pine was the rule before white settlement, rather than the exception as it is today.

The old-growth component of southwestern forests has been declining because of decades of timber harvesting, intensification of forest pest epidemics, and increasing severity of wildfires. Pest and wildfire losses can be directly or indirectly tied to suppression of natural fires. Because of the tenuous status of the remnant old-growth component, forest management should emphasize maintaining and improving growing conditions for perpetuating old growth. Furthermore, management programs should begin to create additional old-growth stands from current, younger stands. Because fire was the primary element in sustaining presettlement old growth by controlling fuel levels and stand densities, it should be relied upon again, possibly in concert with mechanical thinning and fuel reduction, to reestablish old growth prominence. However, in this process, large stand density reductions should be anticipated. This may represent short-term economic losses, but will result in a long-term gain in large, high quality timber.

INTRODUCTION

Ponderosa pine *(Pinus ponderosa* Laws. ex Doug.) occupies 8 million acres of commerical timber land in he southern Rocky Mountain States of Arizona and New Mexico (Schubert 1974). Included in this acre-tge is one of the largest continuous pine forests in North America with an unbroken band 25 to 40 miles vide and about 300 miles long extending from north-entral to northeastern Arizona to west-central New dexico (Cooper 1960). In addition to its expanse, other attributes make this a highly valued forest. These include high timber, wildlife, watershed, and recreational values. Many of these qualties are associated with the diversity contributed by old growth. However, during the past century, slow but lramatic changes in the structure and composition of southwestern ponderosa pine have likely altered hese values.

HISTORIC FOREST CONDITIONS

Chronicles from 19th century explorers, scientists, and soldiers described a forest type quite different han what is seen today. Ponderosa pine forests were open and parklike with abundant grass and forb cover dominating the understory (Biswell et al. 1973). Stately, mature pines grew predominantly in small groups. Scattered clumps of young trees occurred infrequently in spaces between these groups. It seems realistic to assume that for the 150 years of historic documentation before the 20th century, and perhaps for centuries prior, most southwestern pine stands had an old-growth component. Furthermore, this component likely made up a large portion of the forest landscape.

Two interrelated, abiotic factors helped maintain this open-structured forest. Climate is a key factor in vegetation development. Regular precipitation patterns in this pine zone usually include enough winter snow to saturate the soils. Winter temperatures are relatively mild with monthly averages slightly above 30 ° F (Schubert 1974) Annual precipitation minimums occur in May and June with many places receiving less than 0.5 inch of rain for each of those months. This dry period is also represented by increasing air temperatures, low humidities, and persistent winds. By early to mid-July, this drought is usually broken by a rainy period. July and August are the wettest and warmest months of the year. As temperatures cool in the fall, another dry period frequently occurs.

Fire is the other factor that has had a great impact on southwestern vegetation. Early explorers observed both lightning and Indian-ignited fures (Cooper 1960), but fire scar records from the ponderosa pine zone document fire history more precisely. These records authenticate the long-term recurrence of extremely short fire intervals. Within designated sites, mean

fire intervals of 6 to 7 years have been documented in east-central Arizona (Weaver 1951), 2 to 3 years in north-central Arizona (Dieterich 1980), and 5 to 6 years in southwestern New Mexico (Swetnam and Dieterich 1985). Most southwestern ponderosa pine fire scar chronologies point to only a few periods as long as 15 to 20 years without fires during several centuries prior to 1900. These have been associated with abnormally wet cycles (Swetnam and Dieterich 1985).

The typical climatic patterns and presettlement vegetation dictated the frequent return of fire. The continuity of grass and pine litter fuels, frequent lightning, and the warm, dry spring and early summer weather contributed to high fire frequency (Pyne 1982). Highly flammable litter fuels built up rapidly after surface fires. Grasses resprouted and needle cast occurred annually providing fuel for subsequent ignitions. Large, woody fuels rarely accumulated over extensive areas. Mortality of large trees from surface fires was unlikely, and crown fires were exceptionally rare (Biswell et al. 1973). This was apparent even during the drought years of 1903 and 1904, when north-slope spruce-fir types were ravaged by crown fires, but south-slope pine stands survived (Kallander 1969). General tree mortality during presettlement times was usually the result of lightning, dwarf mistletoe, insects, windthrow, or senescence with old age. When single or small groups of trees died and fell, they were consumed by the inevitable surface fires. This more severe, but localized, fire treatment produced mineral soil seedbeds and reduced grass competition, creating a favorable microsite for ponderosa pine seedling establishment (Cooper 1960). Generally, tree seedlings died while competing with established grasses or were burned in fires, but within severely burned microsites with little fuel buildup, a few groups of seedlings infrequently survived. As these seedlings grew, their competitive ability kept grasses from flourishing nearby. In addition, as the pines aged their resistance to fire increased quickly. This pattern resulted in an uneven-aged forest with small, relatively even-aged groups (Cooper 1960).

POSTSETTLEMENT FOREST CHANGES

Changes in the old-growth ponderosa pine forests of the Southwest began during extensive livestock grazing in the late 19th century (Faulk 1970). Most herbaceous vegetation could not survive the intensified grazing, and its coverage declined drastically. This vegetation decline subsequently led to reduced fire spread because of the decrease in fine fuels, and an eventual increase in ponderosa pine regeneration because of reduced competition and fire mortality, and more mineral seedbeds (Cooper 1960). In the early 1900's forestry practices, including fire suppression, further reduced the spread of fires, leading to unprecedented fuel accumulation and stagnation of seedling and sapling thickets (Biswell et al. 1973).

The ponderosa pine forests that have developed in response to these changes bear little similarity to the presettlement forest. In the uncut or lightly harvested stands, some old-growth trees remain. The open structure is gone, however, as dense sapling thickets and small pole groups have developed in the understory. Stand stagnation has been reported on many sites as several thousand saplings per acre are commonplace (Cooper 1960; Schubert 1974). Stagnation persists without natural or artificial thinning. Extremely slow growth is apparent with these stand densities. One northern Arizona site with over 5,000 stems per acre had 43-year-old trees that were growing at a rate of 1 inch in diameter in 33 years (Schubert 1971). After thinning to less than 500 stems per acre, the largest trees responded with a growth rate of 1 inch in 4 to 5 years, possibly representative of presettlement growth.

Slow growth indicates low vigor, high stress, and generally poor health, not only for the dense sapling class but also for adjacent age classes because of intense competition for moisture and nutrients. Older trees are susceptible to disease and insect attacks when they are highly stressed. Primary examples in the Southwest include armillaria root rot and mountain pine beetle (Schubert 1974). In addition, dwarf mistletoe is a major cause of mortality in the ponderosa pine belt. It can kill trees of all age classes. Fire was considered the primary natural control agent of dwarf mistletoe by thinning and pruning diseased trees (Hawksworth 1961). Without frequent fire, mistletoe infestations have increased substantially. Schubert (1974) states that disease (primarily dwarf mistletoe) and insects (primarily bark beetles) account for more than 75 percent of the Southwest's ponderosa pine sawtimber mortality. In addition to stand changes, 75 to 100 years of general fire absence has also led to abnormally large accumulations of surface and ground fuels (Kallander 1969).

The natural accumulation of pine needles and woody fuels is exacerbated by the very slow decomposition rates characteristic of the dry southwestern climate. The steady state weight of dead forest floor fuels, a level at which organic matter inputs equal organic matter decomposition loss, can range from 9 tons per acre in sapling thickets to almost 50 tons per acre on old-growth sites. Annual fuel accumulation on those sites ranges from less than 0.6 ton per acre per year to more than 3.5 tons per acre per year (Sackett and Haase, in preparation). The decomposition rate (k) (Jenny et al. 1949) is the ratio of steady state forest floor weight to the annual accumulation weight. The characteristics of needle litter and small woody fuel for 17 ponderosa pine overstory stands are:

	Sapling	Pole	Old growth
Steady state forest floor (tons/acre)	14.3	24.4	42.6
Annual forest floor accumulation (tons/acre)	1.09	1.43	2.12
Decompositon rate (k)	.076	.059	.050

These k values are considered quite low (Olson 1963). High decomposition rates, where k approaches 1.0, occur in very warm, humid climates.

Sackett (1979) reported average loadings of naturally created fuels at 22 tons per acre (ranging from 8 to 48 tons per acre) for 62 southwestern ponderosa pine stands. Harringon (1982) verified the heavy fuel loading, finding an average of 34 tons per acre in southeastern Arizona. Another formerly uncommon feature is the abundance of large, woody fuels, averaging about 8 tons per acre. Much of these down, woody fuels have accumulated in sapling thickets, creating an even greater probability for crown fires.

The changing forest conditions have altered the herbaceous understory as well. The open, parklike structure of presettlement stands was accompanied by a luxuriant herbaceous layer. With more area occupied by ponderosa pine, understory vegetation has significantly diminished, reducing forage for wildlife and livestock (Arnold 1950). One study in northern Arizona showed that in an unmanaged condition, a stand with 210 square feet of basal area per acre produced no forage, whereas an adjacent stand thinned to 30 square feet produced 470 pounds of forage per acre per year (Schubert 1974).

In the past, pine regeneration generally developed in stand openings after fire had produced a grass-free, mineral seedbed. Now, when trees die creating openings in the stand, pine seedlings have little opportunity to become established in the poor quality, organic seedbed (Sackett 1984).

The dense stands and heavy fuel accumulation are the primary contributors to the increasing number of severe wildfires. Examples include the 1951 Gila Black Ridge Fire (40,000 acres), the 1956 Duddly Lake Fire (21,000 acres), the 1971 Carrigo Fire (57,000 acres), and the 1977 La Mesa Fire (15,000 acres) (Biswell et al. 1973; Cooper 1960; USDA 1977). More recently, six lives, many structures, and numerous acres were lost in the 1990 Dude Fire near Payson, Az. Fire reports from all southwestern agencies further reveal the increased potential for damaging wildfires. During the 75-year period from 1916 to 1990, wildfires burned over 100,000 acres is each of 16 years. Nine (56 percent) of these 16 large fire years have occurred in the last 12 years. Eleven (69 percent) have occurred in the last 20 years. This increase has taken place despite impressive advances in fire detection and suppression technology. In the first half of this century, the impacts of high-frequency, low-intensity fires were still apparent. Fuel and stand conditions had not yet deteriorated to hazardous levels, and intermittent cool, moist periods reduced the fire danger. More recently, with widespread hazardous fuel conditions, droughtlike weather has made large wildfires a regular occurrence. Old-growth trees, which survived numerous presettlement fires, now commonly succumb to high-intensity crown fires.

In summary, changes within the past century have resulted in several undesirable conditions in the southwestern ponderosa pine forests. Extreme fuel hazard is probably most apparent. Heavy forest floor fuel loadings and dense sapling thickets combine with the normally dry climate and frequent lightning- and human-caused ignition potential to create a severe wildfire threat (Biswell et.al. 1973; Harrington 1982). Additionally, trees of all sizes have generally poor vigor and reduced growth rates (Cooper 1960; Weaver 1951). Reduced soil moisture availability caused by intense competition and by moisture retention in the thick forest floor likely contribute to the stagnation (Clary and Ffolliott 1969). The thick forest floor also indicates that soil nutrients (especially nitrogen) are bound in unavailable forms, possibly resulting in nutrient deficiencies (Covington and Sackett 1984).

MANAGING OLD-GROWTH STANDS

The need to alleviate the stagnated and hazardous forest conditions was recognized decades ago (Cooper 1960; Weaver 1951). Much of current mortality of large ponderosa pine can be related directly or indirectly to fire exclusion for at least 75 years. For example, dwarf mistletoe, once held in check by periodic fires, is now a major cause of mortality. In addition, associated growth reduction and stress have resulted in destructive bark beetle epidemics. This stress is related to high competition due to over-stocked stands, which was previously insignificant because of regular thinning by fire. A third significant cause of mortality is fire injury. The number of acres burned by wildfires fluctuates from year to year depending on climate, but a recent trend of increasing acres burned is apparent. Fires which formerly passed undramatically through the understories of these forests, now burn uncontrollably through the crowns of dense stands.

Southwestern forest conditions have been altered largely as a result of fire exclusion. The reintroduction of fire should figure into any attempt to relieve this condition. Management activities, including fire, must be evaluated for stands of all ages to provide optimum conditions for sustaining remnant old growth and to provide opportunities for establishing future old growth. This is because of the closeness and interaction of stands of different age classes. Widespread use of fire to achieve specific management goals has proceeded slowly. A shortage of prescription guidelines and insufficient fire effects information contribute to this reluctance.

Fuel Reduction

The use of prescribed fire for hazard reduction increased from the early 1950's to the early 1980's However, concerns about smoke have led to burning constraints in recent years. Some of the earliest prescribed fire programs began on the Fort Apache Indian Reservation. Over 300,000 acres, containing primarily natural fuels with some logging slash, were burned from 1950 to 1970 for fuel reduction (Kallender 1969). A dramatic decline in wildfire size

and severity resulted (Biswell et al.1973; Knorr 1963). Weaver (1952) reported that the number of wildfires in west-central Arizona was limited after prescribed burns consumed 55 to 80 percent of duff and nonslash woody fuels.

One important concern deals with the direct relationship of fuel consumption and tree injury. In one fire impact study, a relatively low- intensity, moderate-severity burn in Arizona ponderosa pine reduced surface, ground, and aerial fuels by 57% percent (Gaines et al. 1958). A contrasting burn under more severe weather and fuel moisture conditions initially consumed more fuel. However, when the fire-killed foliage, branches, and trees were added to the remaining surface fuel several years later, the reduction was only 15 percent. Documentation from two additional prescribed burning projects substantiated this finding. Burning in central (Davis et al. 1968) and west-central Arizona (Lindenmuth 1962) left sites with sufficient fuel reduction initially. After tree mortality, however, the net fuel loss on the sites was minimal.

Sackett (1980) and Harrington (1987) emphasized the important relationship of moisture content and consumption of forest floor fuels. Stand density and overstory type are also contributing influences. For example, with similar fuel moistures, forest floor reduction was 34 percent in sapling thickets, 52 percent in pole stands, and 89 percent in old-growth stands (Covington and Sackett in press). Because old-growth stands generally have the greatest forest floor loadings, this potentially high fuel consumption could represent a substantial impact, which will be discussed later.

Besides surface and ground fuels, extensive ladder fuels add to the fire hazard. In fact, it is this component that takes a surface fire into the crowns of the overstory, including the old growth. Vertical continuity can be broken with proper fire application. Some important live fuels are medium- sized shrubs, which are easily top-killed, but generally resprout. Gambel oak, for example, is quite flammable, but its height and canopy coverage can be kept low by repeated burning (Harrington 1985).Low crowns of ponderosa pine sapling thickets also increase crown fire threat. Scorching the lower portion of sapling canopies helps relieve this hazard, but the procedure is difficult (Harrington 1981).

Initially, the fuel hazard in these pine stands can be substantially reduced with understory burning. Removal of the litter layer reduces potential rates of fire spread and ignition. Reduction of duff, woody material, and ladder fuels decreases potential fire intensity, total heat release, and resistance to control. However, the fuel hazard is only temporarily reduced as up to 2 tons per acre of fine fuels are normally cast annually. Decidedly more can accumulate from fire-injured trees. This latter accumulation is the consequence of inevitable tree injury caused by consumption of unnaturally high fuel quantities in unnaturally dense stands. Consequently, repeated burning is essential to remove these fire-created fuels and generally maintain a low fuel hazard. More detailed information on prescriptions and burning techniques can be found in Harrington and Sackett (1990).

Stand Density Reduction

Since the early 1900's, the remnant old-growth ponderosa pine stands that survived extensive logging and wildfire have been invaded by a profusion of pine regeneration. Reducing the densities of sapling thickets that cover millions of acres in the Southwest would produce many benefits. Besides reducing the crown fire hazard, herbaceous vegetation could be increased as more light and moisture become available (Clary and Ffolliott 1966).Because these "dog hair" thickets have encroached into old-growth sites, substantial decreases in the number of tree stems would lessen competition, possibly improving the health of young and old trees. Finally, most forest visitors find the dense stands inaccessible and esthically unappealing (Brown and Daniel 1986).

Managers have few options for reducing densities of these stands. Commercial thinning for pulpwood is possible where trees have grown into usable size. Precommercial thinning is probably the most common practice, but it is not economically feasible over extended areas. Additionally, the fuel resulting from large-scale thinning would encourage insect epidemics and create severe wildfire hazards. Obviously, no single treatment is the answer. The problem must be approached with a number of methods, depending on the circumstances and present conditions.

Thinning by fire was a natural process in ponderosa pine before white settlement (Cooper 1960). However, today's stand and fuel conditions are a drastic contrast to turn-of-the-century conditions. Fire thinning operations are complex, uncertain, and frequently viewed as wasteful, particularly given the high value placed on timber products. Guidelines for using fire as a thinning tool are scarce. Even though the smallest and least vigorous trees are the first to succumb to fire injury, fire is generally not very selective. A patchy stand with characteristics that cannot be predicted usually results. Most studies dealing with fire as a thinning agent have lacked a long-ranged process to accomplish the objectives. A number of fires are usually required to reduce fuels, change the stand structure, and overcome other alterations caused by decades of fire exclusion.

Several investigators have observed both positive and negative aspects of fire thinning. Weaver (1947) reported that 30 years after burning, a young ponderosa pine stand had fewer stems per acre, greater heights, and larger diameters than an adjacent unburned stand. In another study, Gaines et al. (1958) reported that even though younger, suppressed classes had been thinned, the commercial overstory suffered substantial injury. Lindenmuth (1962) studied the effects of fire in east-central Arizona and concluded that 24 percent of the potential crop trees were released from competition, but 17 percent were killed or severely damaged. Ffolliott et

al. (1977) reported that a positive thinning response followed prescribed fire in northern Arizona, but basal area was not reduced enough for optimal stand stimulation. Clearly, most research points out the imperfect nature of fire as a thinning mechanism. However, a single fire cannot be expected to correct forest stagnation that has occurred in the past 100 years. Additonal information on burning techniques and thinning prescriptions is found in Harrington and Sackett (1990).

Thinning was also an important benefit in a more recent prescribed burning study in southeastern Arizona designed to reduce fuel hazards. A comparison was made between the impact of three distinct fires on sapling thickets and old-growth groups (Harrington 1981). The fires reduced tree densities by 24, 43, and 56 percent in stands with total fuel reductions of 13, 18, and 22 tons per acre, respectively, implying a relationship between fuel reduction and stand density reduction. Basal area in the old-growth groups was reduced only 2 percent, indicating that with a 26 percent reduction in stems per acre, most mortality was in the small size classes. However, observations several years after prescribed burning have revealed results that need special attention.

The impacts of 75 to 100 years of fire suppression can have quite serious impacts when fire is reintroduced into old-growth ponderosa pine. Frequent fire intervals of presettlement times (2-5 years) kept fuel accumulations to a minimal level (2-8 tons per acre) at the bases of mature trees. Today, total litter and duff accumulations in old-growth groups can amount to 30 to over 70 tons per acre.

Even though there are valuable fuel hazard, nutrient, thinning, and regeneration benefits derived from the consumption of heavy forest floors, there are also liabilities. Consumption of large quantities of fuel generates large amounts of heat. Studies at Fort Valley and Long Valley Experimental Forests in Arizona show very high mineral soil temperatures during burning (Sackett and Haase, in preparation). Lethal temperatures have been measured deeper than 8 inches in the mineral soil on some sites. The first burn in 100 years at the Chimney Spring Prescribed Fire Research Area at Fort Valley killed almost 40 percent of the old-growth ponderosa pines, which had survived numerous presettlement fires. Mortality did not appear until several years after the burns and has continued to be greater than on unburned sites.

Fires burning under these old-growth pines are often unspectacular, consuming only the litter layer in the flaming front. Most of the forest floor is consumed by smoldering combustion, which often goes unnoticed. As smoldering continues for up to 72 hours, ash is formed from the top down, creating an insulating cover. The insulation prevents heat from escaping causing it to penetrate the mineral soil. Burning for long time periods can result in either temperatures exceeding 140 °F, which causes instant cambium or root death, or lower temperatures for longer durations which also can kill plant tissues.

Fuel loadings ranged from 32 to 86 tons per acre where temperatures were measured under old pines at Fort Valley and Long Valley. Consumption was always greater than 85 percent despite humus moistures up to 90 percent. In 22 of 25 cases, the temperature 2 inches below the soil surface reached 140 °F. At the 8-inch depth, temperatures exceeded 100 °F in 21 cases and averaged 138 °F. Even at 12 inches below the soil surface, temperatures greater than 11.5 °F have been reached.

Tree cambium can also be affected by forest floor consumption. Sloughed bark along with heavy duff compressed against the tree's bole generate additional heat during burning. Temperatures measured at the cambium where forest floor material is being consumed range from 61 °F to 231 °F. The average for 14 test fires was 144 °F, high enough to kill the cambium.

MANAGEMENT IMPLICATIONS

Forest management in the Southwest should include objectives that maintain or improve existing old-growth stands and that also begin to create supplemental old growth. Trees more than 200 years old are relatively scarce outside of research natural areas, experimental forests, and wilderness because of timber harvesting, and mortality from wildfire, insects, and disease. Therefore, the emphasis in forests managed for multiple use should be to generate conditions that will allow existing stands to development into healthy old-growth stands. Concurrently, growing conditions should be improved in the remnant old growth within experimental forests and wilderness areas and on isolated sites under general management.

Because recurrent fire was a primary element in sustaining presettlement forest health leading to the establishment and maintenance of old-growth stands, its use should be emphasized when restoring favorable conditions for ancient pine development. These conditions include low levels of dead organic matter (fuels) to lessen the potential of high fire intensity and severity, and open stand structure to reduce crown tire potential and intraspecific competition. Fire can be used to reduce fuel hazard, but its success has been uncertain and temporary. Failures denoted by too little or too much fuel consumption generally result from improper burn prescriptions and attempting to correct long-term fuel buildup with one treatment. Cooper (1960) questioned whether prescribed fire could be used in the restoration of deteriorated forests. He concluded that planned burning would either be too conservative and accomplish little, or would destroy the stand. While this observation has merit, with refined burning techniques as described in Harrington and Sackett (1990), it appears that fire could be applied sequentially to relieve the unnatural fuel and stand density status. However, it is apparent

that considerable tree mortality will result, possibly representing an economic loss "his seems to be an inescapable cost, dictated by a century of forest degradation.

In extensive forest regions where old-growth pine groups are absent, designated areas based on site quality and existing stand types should be selected for creating future old growth. The best growing sites should be chosen because old-growth characteristics would be achieved more expeditiously there than on poor sites. Moir and Dieterich (1990) suggested that 150- to 200-year-old blackjack pines in open stands with no dwarf mistletoe be selected as the best stands to begin developing old growth. Through sequential silvicultural and fire treatments, the stands should be relieved of wildfire hazards and competition, allowing concentrated growth on a chosen group of trees. A long-term commitment is necessary, because another century may be needed before select old-growth pine is represented (Moir and Dieterich 1990). If younger stands are chosen for old-growth replacement, a greater commitment of time is required for thinning, slash disposal, commercial harvesting, and fire application.

Special attention should be given to the unnaturally excessive buildup of forest floor fuels in present old-growth sites. As mentioned, burning of these deep forest floor layers can mortally injure the roots and cambium of old pines, which previously survived many fires. Options for alleviating this atypical condition are not ideal. Managers could simply accept a 20 to 50 percent loss of old growth in a single fuel reduction burn as a cost of decades unnatural fuel buildup. Alternatively, heavy fuels could be manually reduced from the forest floor around old-growth groups before fire is used. This option would be limited by cost. Lastly, under the right fuel moisture conditions, fire might be used to peel the forest floor one layer at a time, eliminating the impact of a onetime heat shock. This option is speculative, since it has not been specifically attempted. If presettlement ponderosa pine stand and fuel conditions are approached, regular burning must be practiced to allow fire to play the primary role in sound ecological maintenance.

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